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An Assessment of the Scale Damage to and Survival Rates of Young Gadoid Fish Escaping from the Cod-end of a Demersal Trawl

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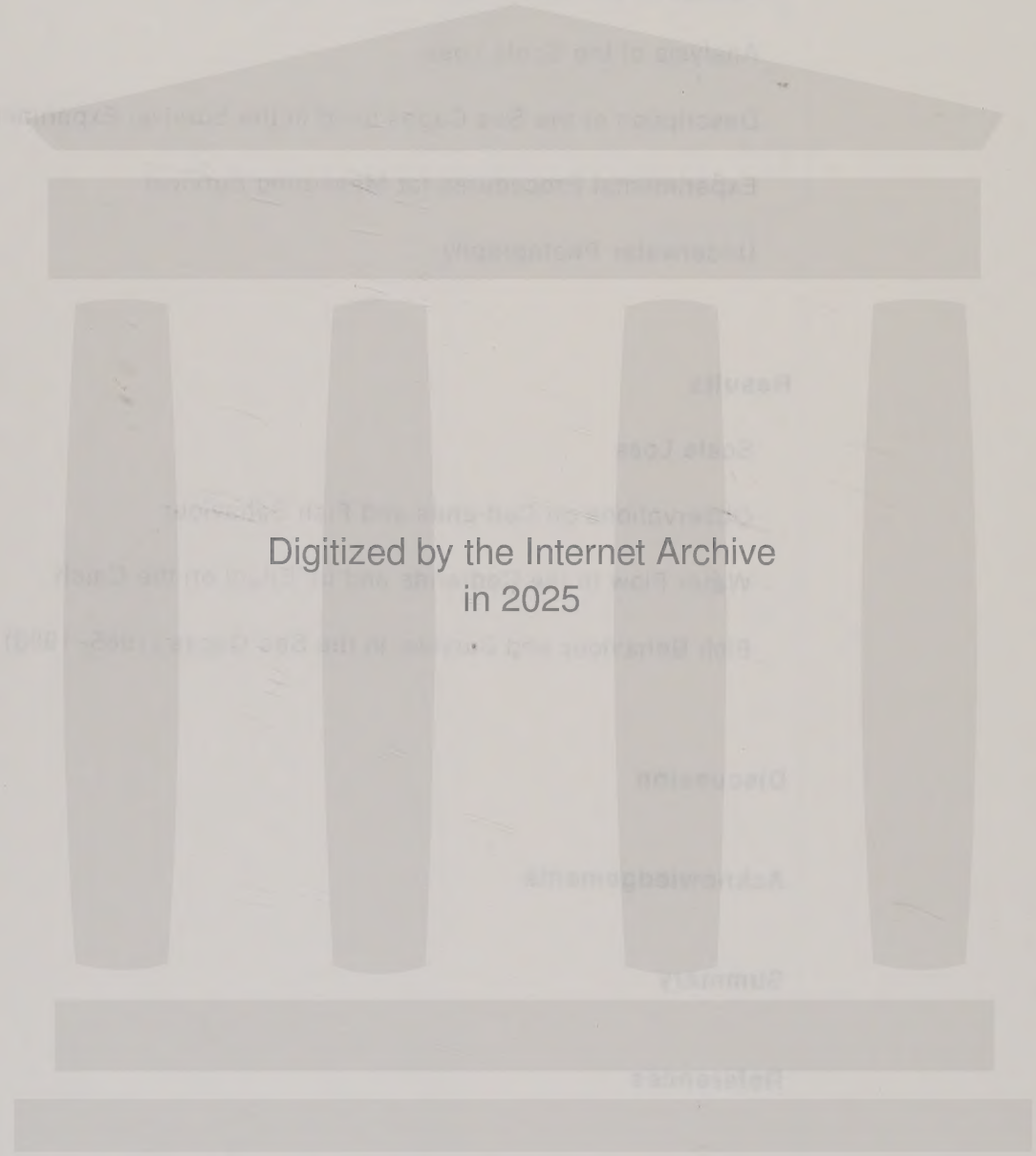
CONTENTS

	Page
Introduction	1
Materials and Methods	3
Fishing and Diving	3
Collection of Fish for Scale Loss Assessment	4
Analysis of the Scale Loss	4
Description of the Sea Cages used in the Survival Experiments	6
Experimental Procedures for Measuring Survival	7
Underwater Photography	9
Results	10
Scale Loss	11
Observations on Cod-ends and Fish Behaviour	16
Water Flow in the Cod-ends and its Effect on the Catch	19
Fish Behaviour and Survival in the Sea Cages (1985–1988)	20
Discussion	25
Acknowledgements	26
Summary	27
References	28



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An assessment of the Scale Damage to and Survival Rates of Young Gadoid Fish Escaping from the Cod-end of a Demersal Trawl

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Introduction

When fish enter a code-end, some are retained while others escape. If a fish is very large relative to the cod-end mesh size it will be caught, and if it is very small relative to the mesh size it should escape. In practice, however, many small fish do not escape from cod-ends. This is due either to fatigue caused by the enforced swimming activity created by the visual stimulus of the trawl (Wardle, 1983), to the meshes being partially closed or even blocked by other fish present in the cod-end (Main and Sangster, 1984), or to cod-end design, which can limit the area of open meshes (Robertson and Ferro, 1988).

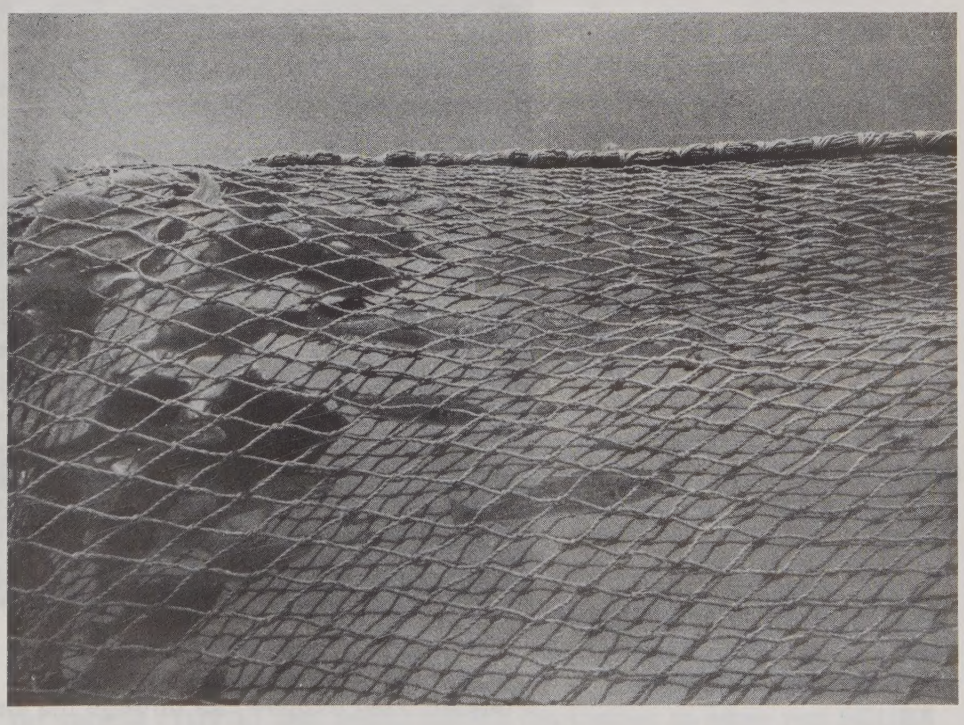


Plate 1. Near empty cod-end showing the slack and open shape of the meshes.

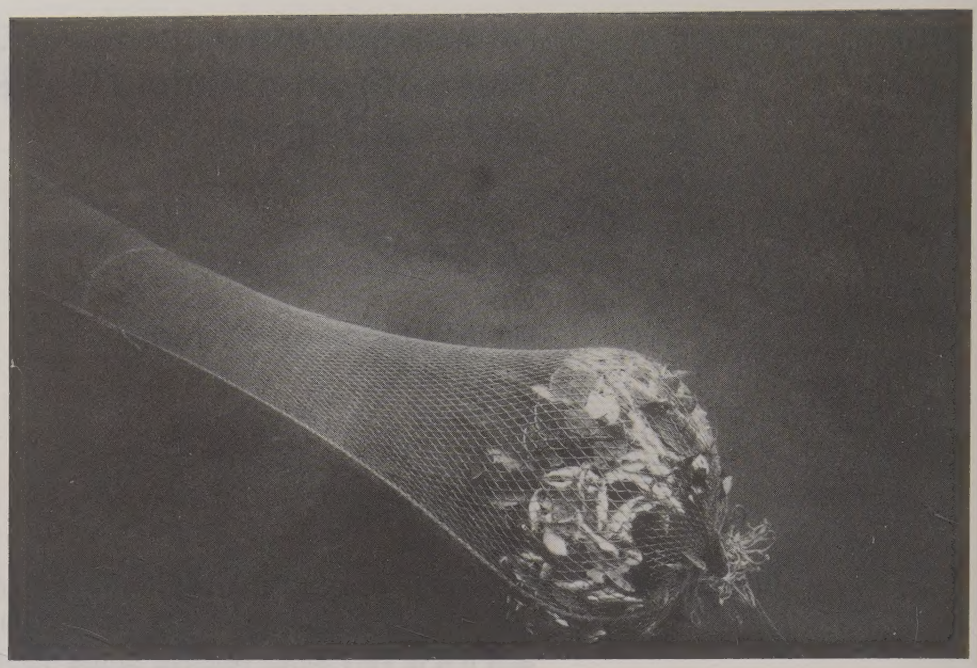


Plate II. Cod-end , partially full, showing the elongated shaped meshes in the fore part and its overall bulbous shape.

Plate III. Fish trapped half through the elongated cod-end meshes. Fish scales can also be seen billowing around the cod-end.

The shape of a cod-end changes during the duration of a haul (Main and Sangster, 1981). At the start, when the cod-end is empty, the meshes have an open diamond shape with little strain on the material (Plate I). As the catch builds up at the rear of the cod-end, the accumulated bulk and increasing drag draws out the cod-end netting into a pear shape. The meshes in the forward zone become more elongated and closed (Plate II), reducing fish escapes in this area. In this situation, small fish have to encounter unblocked meshes near the rear of the cod-end in order to escape. Their time in the cod-end may be prolonged, increasing the likelihood of superficial damage by abrasion either on the meshes or by contact with Crustaceans (eg *Nephrops norvegicus* (L.)) or rough skinned species (eg dogfish *Scyliorhinus caniculus* (L.) and gurnards *Eutrigla gurnardus* (L.)). Direct observations of fish in cod-ends (Main and Sangster, unpublished) have demonstrated many examples of young gadoids being either permanently trapped half through these elongated meshes or temporarily held back before eventual escape (Plate III). Fish were seen to squeeze themselves through the meshes, resulting in scale removal and damage to their flanks. Often quite large numbers of fish scales were seen billowing around the cod-end.

How badly damaged are the fish that manage to escape from a cod-end? Do the scale-damaged fish recover or die? These questions have never been answered.

Fishery management by mesh size regulation involves the assumption that escaping fish survive and become part of the future spawning biomass. Sea bed tagged haddock, *Melanogrammus aeglefinus* (L.), taken from conventional trawl and seine-net cod-ends were held in cages by Hislop and Hemmings (1971). Survival ranged from 78 to 100%. Further work by these authors on sea bed tagged haddock from a seine-net cod-end produced tagged fish returns from the wild of between 90 and 95%. These high rates of survival were very encouraging and were the basis for the use of tagged fish in the cage experiments reported here, which began at the Marine Laboratory in 1985. This paper describes the techniques used in the experiments and presents the results of a study of the scale damage and survival of young gadoid fish escaping from various sizes of cod-end on a demersal trawl.

Materials and Methods

Fishing and Diving

Bottom trawling took place between 1985 and 1988 on grounds near Gairloch, Scotland, in depths between 25 and 40 m. A rockhopper trawl was used to collect the fish for both the scale damage investigation and the survival experiments.

Cod-ends with nominal inside stretched mesh lengths of 70, 80 and 90 mm diamond mesh and 80 and 90 mm square mesh were used. Details of these cod-ends are presented in Table I. A diver operated underwater vehicle (TUV-II) was towed behind the trawler to allow two SCUBA divers protected access to the cod-end area for sampling, observing and filming (Main and Sangster, 1983). Diving safety procedures and their operational techniques used on fishing gears are discussed in Main and Sangster (1978) and Anon (1988). Trawling was usually conducted at a towing speed of 1.5 ms^{-1} (three knots) and the duration of each haul was never more than one hour.

Table I

Details of the cod-ends used in the experiments

Mesh	Size (mm)		Twine	Meshes on round	Cod-end length (m)
	Nominal	Actual			
Diamond	70	68.3	Single polyethylene	120	4.2
Diamond	80	79.4	Single polyethylene	120	4.2
Diamond	80	78.4	Double braid polyethylene	120	4.2
Square	80*	80.5	Double braid polyethylene	120	4.2
Diamond	90	85.6	Double braid polyethylene	120	4.2
Square	90*	86.4	Double braid polyethylene	120	4.2

* measured on the stretched diamond

Collection of Fish for Scale Loss Assessment

To investigate scale damage, single fish seen passing through a cod-end mesh were caught by the divers using a transparent polythene bag and immediately killed by the addition of a strong solution of anaesthetic (1 g l^{-1} 3-Aminobenzoic acid ethyl ester, MS222). This anaesthetic was administered to the sea water-filled bag, containing the single fish, from a syringe-type reservoir flask housed inside the TUV II. This rapid method of killing each specimen ensured that no further scale loss occurred during captivity in the bag. Each pre-numbered bag containing a single fish was closed with a plastic lock-action tie and stored carefully within the TUV II. The operation was repeated until sufficient numbers of fish (approximately 8–10 specimens for convenience of handling) were caught or diving time was used up. On completion of each dive, the specimens were returned to the towing vessel to be examined, measured and photographed. Assessment of scale loss was not investigated in 1988 owing to the complexity of other parts of the experimental programme.

On some fishing hauls, a small mesh cover (40 mm stretched mesh) was fitted over the cod-end. On completion of these hauls, samples were taken from the cod-end and cover on deck for length and girth measurements and from the cod-end alone for scale damage assessment. The scale damaged fish were immediately transferred from the cod-end to a sea water tank on the ship and categorised as "cod-end retained", to be compared with those samples caught *in situ* escaping from the cod-end.

Analysis of the Scale Loss

Each dead specimen was removed carefully from its water-filled polythene bag, ensuring that no part of the flank regions sustained further scale loss. No scales were recovered from the bag's sea water contents. Both sides of the fish were visually sub-divided as shown in the illustration in Figure 1 and an indicator of scale loss in each of the 10 zones per flank was assessed on a simple zero to ten scale (relating to 0%–100% scale loss).

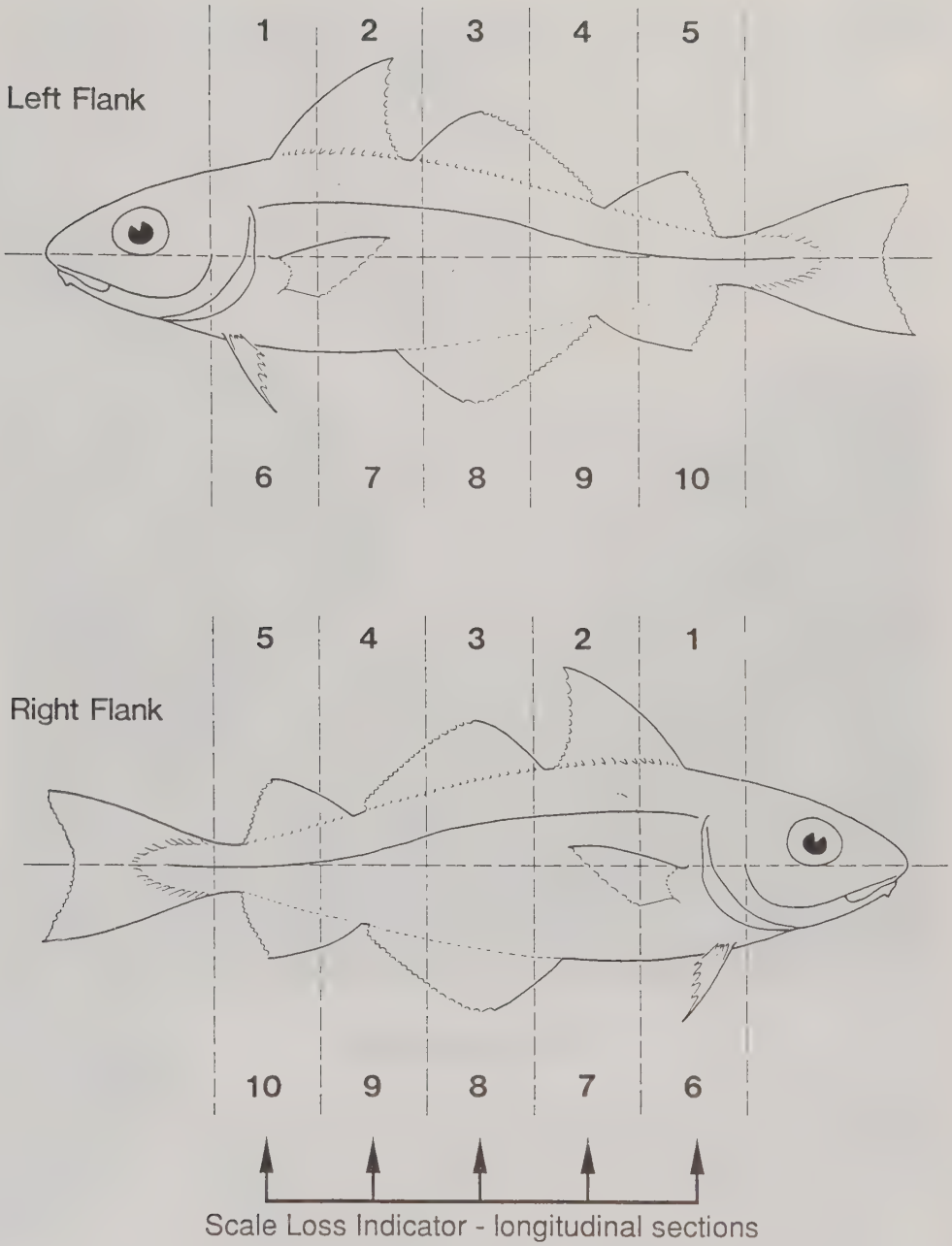


Fig. 1 Template used to record the information of scale loss on each individual fish

The indicators for the upper and lower areas of each section were used to estimate a percentage scale loss for each of the five longitudinal sections on both flanks (Fig. 1). The mean value of these ten percentage scale losses was then calculated, giving an overall scale loss indicator for each fish. This indicator tends to be an overestimate of actual percentage scale loss for the fish since the longitudinal sections are not equal in area and in general the smaller areas show greater scale loss.

The length and maximum girth of each specimen were also measured and some were photographed to demonstrate different examples of damage. Scale loss, species, length, girth and sample category could then be compared against mesh size and any specific pre-recorded escape behaviour.

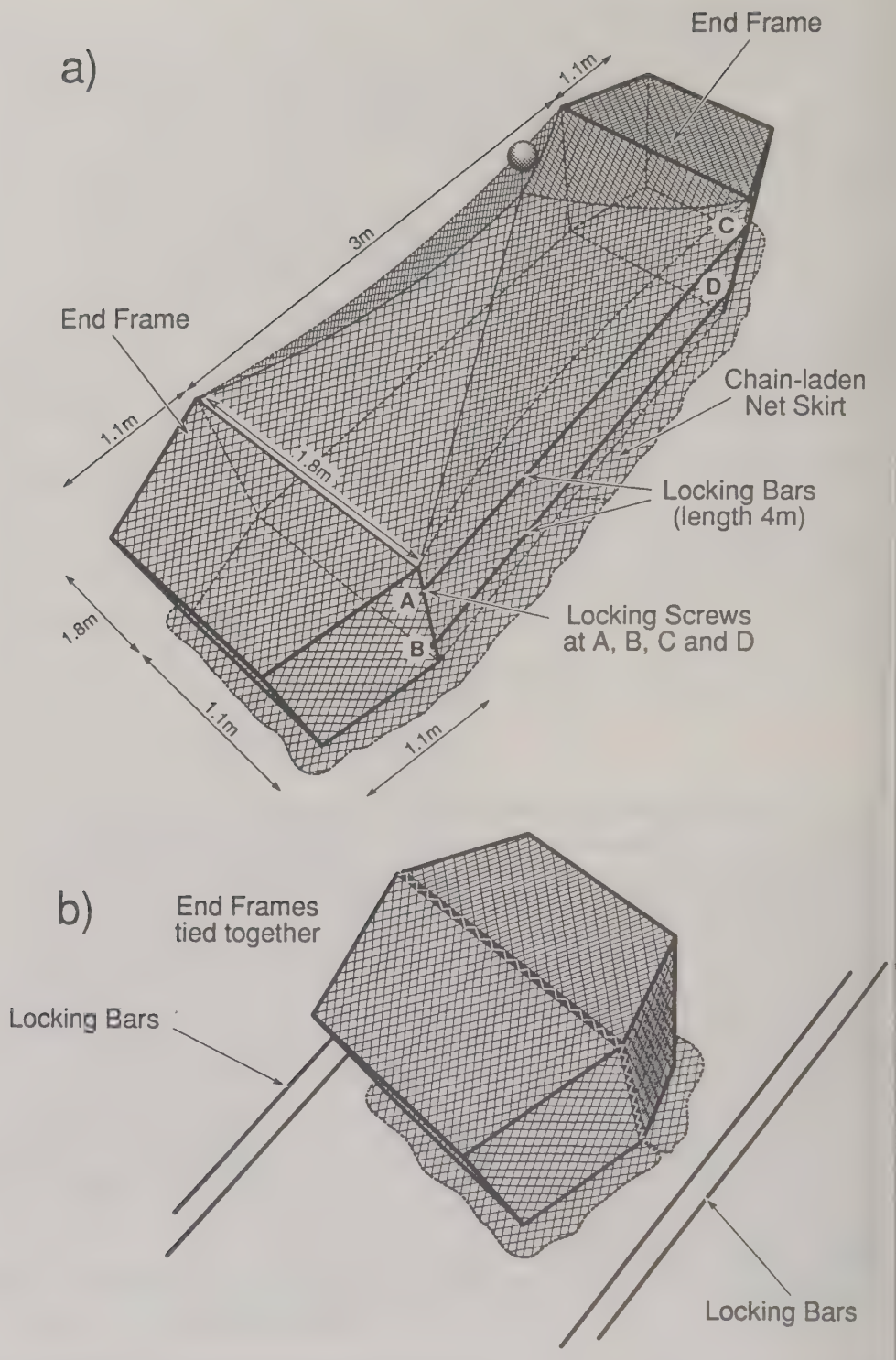


Fig. 2. **a) Fully erected sea cage.**
b) Partially collapsed cage, ready for transportation to the cage site.

Description of the Sea Cages used in the Survival Experiments

Figure 2a shows the shape and dimension of the sea bed cages. The 17 m^3 tailored net cage was suspended inside a partly demountable metal structure. This design ensured that no metal surface would abrade the captive fish. The cages had no floor netting but a loose skirt was attached all round the side wall netting and weighted down by stones and chain. The absence of floor netting guaranteed that fish were in contact only with the natural substratum. The end-walls were made of small-mesh (10 mm) white knotless nylon netting, allowing the captive fish the best opportunity to see tham and hence minimise contact with the netting. This small mesh would also reduce any strong tidal water flow through the cage and provide some shelter. To

minimise abrasion the main body netting of the cage was constructed in soft nylon (50 mm stretched mesh) rather than in hard polyethylene type twine. After assembly and rigging on land, each complete cage was partially collapsed by slackening and removing the locking bars as in Figure 2b, ready for transportation by a Zodiac inflatable boat to the sea bed site. The site was chosen as near to the fishing areas as was practically possible (approximately 2 km). On arrival at the site, the cages were lowered to the sea bed, erected, anchored and marked by buoys. As a precautionary measure, two small floats were attached to the top of each cage to prevent the roof netting from sagging (Plate IV).

Plate IV. Sea cage fully erected on the sea bed

Experimental Procedures for Measuring Survival

Fish escaping from the various cod-ends ("escapes") were collected by the divers from the TUV II and transferred at depth in large black polythene bags to the cages on the sea bed for survival assessment. Fish caught in the cod-end ("retained") were transported to the cages by detaching the cod-end under water and slowly towing it to the sea bed site. "Control" fish were caught by barbless hook and line and transferred to the cage site.

In these circumstances the main difference between control and experimental fish would be the experience of being in, and escaping from, a trawl. The degree of fatigue and stress of each fish on entry to the cage might, however, vary for both classes of fish. In 1986 individual specimens of hand-line damaged haddock were caught and introduced into a sea-cage. Survival comparisons between trawl damaged and line damaged fish could then be assessed.

In 1988 the experimental procedure was slightly altered to include an extra group of "tagged control" haddock. These were caught by barbless hook and line from 30 m depth and introduced into all the cages, including the control cages, to check whether the cause of death in any one particular cage was from some form of infection due to its position on the sea-bed, rather than to the process to which the fish had been subjected. Each fish was tagged (flag type) through the skin, ahead of the first dorsal fin (Plate V). After tagging the fish was passed through a bath of Malachite green to prevent infection to the wound (1 g Malachite green to 450 ml sea water).

Plate V. Haddock swimming in one of the sea cages. The fish in the centre of the picture has a flag type tag fixed ahead of its first dorsal fin.

Plate VI. The multi-monofilament small mesh cod-end cover showing the hooped arrangement which allows adequate space for escaping fish and does not mask the cod-end meshes.

Furthermore, in 1988 a specially designed small mesh cover (40 mm stretched multi-monoflament nylon) was fitted over the trawl cod-end to hasten the collection of escaped fish. This attachment (Plate VI) was developed and tested to maintain a good flow of water along the outside of the cod-end. It also provided adequate space for the escaping small fish to enter the holding area at the rear of the cover without suffering further damage. The attachement of the cover to the net was by four one metre rope strops fitted with quick-release clips. On completion of the haul, two divers attached a tow rope to the cover, detached it and tied it off at the front end to prevent fish escape. The cover containing the fish was then slowly (<0.25 m s $^{-1}$) towed, at depth, by a small boat to the cage site where the divers transferred the required fish into the appropriate cages (Plate VII). When all cages had been stocked the survival experiments began. Visits were made by divers and accurate fish counts obtained from all the cages at least every 24 hours. Food, in the form of chopped sandeels (*Ammodytidae*) was offered to the fish during each diver's visit.

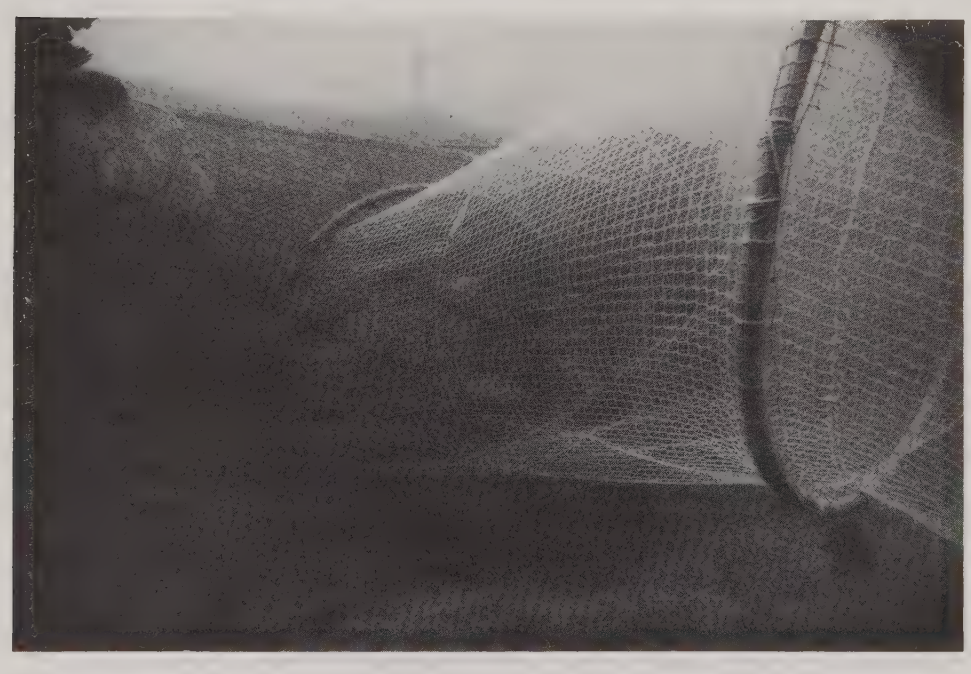


Plate VII. The small mesh cover containing the cod-end escaped fish is held against the zip opening on the side of the sea cage. The fish are counted by the diver as they are simply transferred into the cage.

In 1988 each fish category under investigation was repeated in triplicate. Thirty fish were used per cage, with the addition of 10 tagged fish (including all three control fish cages). The cages were set up in a randomised latin-square layout (ie three rows of three cages). Having 40 fish per cage, the counting of survivors was impractical in the limited diving time available, so only dead fish were counted and then removed daily.

Underwater Photography

Still photographs were taken using a Nikonos V underwater camera fitted with a 15 mm, 28 mm or 35 mm lens. Ilford HP5 35 mm black and white negative film uprated to 800 ASA was used and only natural light was employed throughout the experiments. Video films were taken using a Sony CCD-M8 series camera recorder housed in an MPK-M8 Marine Pack. Eight millimetre video film cassettes of 90 minutes duration were found to be the most suitable for the work. The rechargeable battery packs give continuous usage of the camera for approximately 30 minutes.

Results

Table II shows the species, numbers and origin of fish examined from each cod-end mesh size; whether escaped from cod-end (escapes) or retained in cod-end (deck samples). The length and girth relationships of haddock were obtained for 70, 80 and 90 mm diamond mesh cod-ends (Fig. 3) during three one hour tows in the Gairloch area. Data for fish caught in each cod-end were compared with those for escaping fish which were retained in a small mesh cover. The total selection range was 21–27 cm, 24–32 cm and 24–34 cm for the 70, 80 and 90 mm cod-ends respectively.

Table II

Numbers and species of fish examined from each cod-end mesh size and twine type. Specimens were taken from the cod-end either under water or when it was lifted on to the ship's deck.

Type of cod-end	Haddock	Whiting	Cod	Hake	(Total)
70 mm (single twine) diamond mesh escapes	9	14	0	16	39
80 mm (single twine) diamond mesh escapes	56	39	0	0	95
80 mm (double twine) diamond mesh escapes	27	12	0	0	39
80 mm (double twine) square mesh escapes	23	8	4	0	35
90 mm (double twine) diamond mesh escapes	34	0	0	0	34
90 mm (double twine) square mesh escapes	27	0	0	0	27
80 mm (single twine) diamond mesh (deck samples)	11	0	0	0	11
90 mm (double twine) diamond mesh (deck samples)	46	0	0	0	46
90 mm (double twine) square mesh (deck samples)	57	0	0	0	57
Totals	310	73	4	16	403

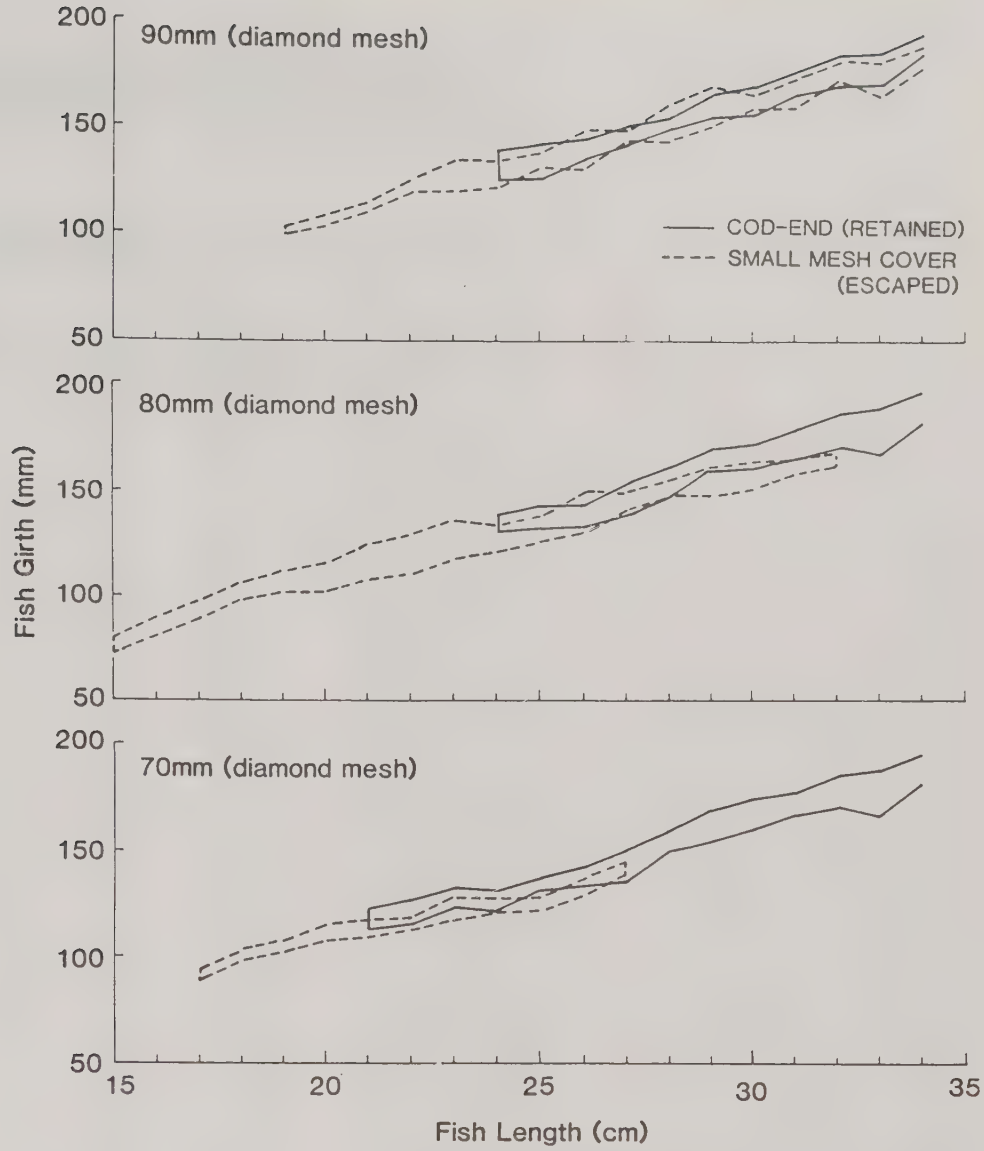


Fig. 3. Haddock length plotted against girth range for fish retained in the 70, 80 and 90 mm diamond mesh cod-ends and the small mesh cover (escapes). (Data from three one-hour covered cod-end trawling hauls)

Scale Loss

To investigate whether scale loss is related to fish size, values of overall percentage scale loss were calculated for each 1 cm length group. The mean values of the percentage scale losses in the five longitudinal sections (Fig. 1) on both flanks of all fish were tabulated for haddock (Table III). Data for whiting (*Merlangius merlangus* (L.)), hake (*Merluccius* L.) and cod (*Gadus morhua* L.) were similarly analysed. There was no clear relation between length and scale loss in any species.

Table III

The overall percentage scale loss tabulated by fish length for haddock escaping from, or retained by, a range of cod-ends. Single or double twine is indicated and the mean girth of each length given

Haddock		Mean percentage scale loss and cod-end size						
		Escaped				Retained		
Length (cm)	Mean girth (mm)	70 mm diamond (single)	80 mm diamond (single)	80 mm diamond (double)	80 mm square (double)	80 mm diamond (single)	90 mm diamond (double)	90 mm square (double)
18	102		50					
19	104	68						
20	107	84	59	64	32		63	
21	112	100	36	26	47			5
22	116	100	45	37	42			
23	121	74	46	33	36			5
24	126		38	46	43		79	6
25	129		66	66	50			8
26	135		68		90		48	4
27	145	90			55		35	5
28	150				50		41	8
29	154				23		52	14
30	157				64		44	10
31	159				57		33	7
32	163				44		34	
33								
34	172						41	
35	177						34	
36								
37								
38	200					13		
39								
40								
41	220					14		
42								
43								
44	235					7		
45	241					14		
46								
47	257					18		
48	260					33		
49	263					16		
50								
51								
52								
53								
54	290					12		

Table IV

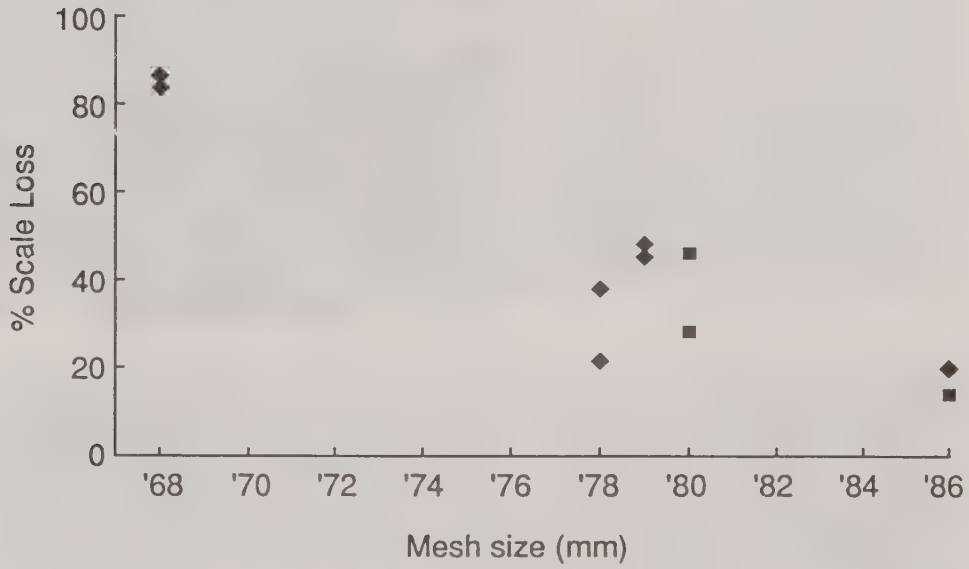
Mean percentage scale loss in each of the five longitudinal sections occasioned by each type of cod-end used. Data for haddock, whiting, hake and cod

Cod-end size (mm) single or double twine	Cod-end type diamond or square	Species and sample type	Numbers and size range (cm analysed)	Right flank (longitudinal section) Tail ---------- Head					Left flank (longitudinal section) Head ---------- Tail					Mean % scale loss	
				5	4	3	2	1	1	2	3	4	5	Left flank	Right flank
70 (single)	Diamond	Haddock (escaped)	9 (19–27)	92	95	92	87	69	74	82	87	82	82	81	87
80 (single)	Diamond	Haddock (escaped)	56 (18–26)	62	60	51	29	22	26	36	48	62	65	47	45
80 (double)	Diamond	Haddock (escaped)	27 (20–25)	51	48	47	28	25	26	29	42	44	41	36	40
80 (double)	Square	Haddock (escaped)	23 (20–32)	57	53	46	38	25	23	30	52	62	67	47	44
90 (double)	Diamond	Haddock (escaped)	34 (22–34)	24	20	20	18	8	10	18	28	28	30	18	23
90 (double)	Square	Haddock (escaped)	27 (21–35)	30	34	20	5	5	2	5	5	15	25	19	10
80 (single)	Diamond	Haddock (retained)	11 (38–49)	12	15	14	8	7	5	15	29	31	22	20	11
90 (double)	Diamond	Haddock (retained)	46 (20–35)	50	52	45	40	35	36	43	48	51	57	44	47

Table IV (continued)

Cod-end size (mm) single or double twine	Cod-end type diamond or square	Species and sample type	Numbers and size range (cm analysed)	Right flank (longitudinal section) Tail ---------- Head					Left flank (longitudinal section) Head ---------- Tail					Mean % scale loss	
				5	4	3	2	1	1	2	3	4	5	Left flank	Right flank
90 (double)	Square	Haddock (retained)	57 (20–33)	2	4	3	3	1	2	4	4	4	2	3	3
70 (single)	Diamond	Whiting (escaped)	14 (17–26)	96	100	98	89	64	67	79	86	92	90	83	89
80 (single)	Diamond	Whiting (escaped)	39 (20–37)	56	52	55	37	18	26	42	52	69	70	52	44
80 (double)	Diamond	Whiting (escaped)	12 (23–28)	16	22	27	20	7	17	18	25	33	30	25	19
80 (double)	Square	Whiting (escaped)	8 (25–32)	24	26	37	24	15	18	25	42	35	29	30	25
70 (single)	Diamond	Hake (escaped)	16 (19–27)	63	70	76	74	51	54	62	85	80	71	70	67
80 (double)	Square	Cod (escaped)	4 (23–46)	25	4	0	1	0	0	4	3	4	25	7	6

Alternatively scale loss may be a function of cod-end mesh size and type. For each category of fish the mean percentage scale loss was calculated for each cod-end type (Table IV). The data showed that the greatest damage to haddock and whiting was caused by the smallest mesh size, ie 70 mm, although few fish were involved. There was little difference in the damage caused to haddock escaping from diamond compared with square mesh cod-ends of similar mesh size. Damage tended to decrease with increasing mesh size (Fig. 4).



Mean % Scale Loss

	Diamond or square	Mesh size (mean)	Haddock	Whiting
70 single	◆	68	84	86
80 single	◆	79	46	48
80 double	◆	78	38	22
80 double	■	80	46	28
90 double	◆	86	20	
90 double	■	86	14	

Fig. 4. The mean percentage scale loss for haddock and whiting plotted against each cod-end type's mean mesh size.

Percentage scale loss in individual longitudinal sections (Table IV) was examined but no correlation with fish size was found for the widest sections (sections 1 and 2). Inspection suggested that damage nearly always tended to increase towards the tail sections, with noticeably less damage in section 1 behind the head (see Table IV, mean percentage scale loss to both right and left flank longitudinal sections). Plate VIIIa—d demonstrates different examples of haddock scale damage.

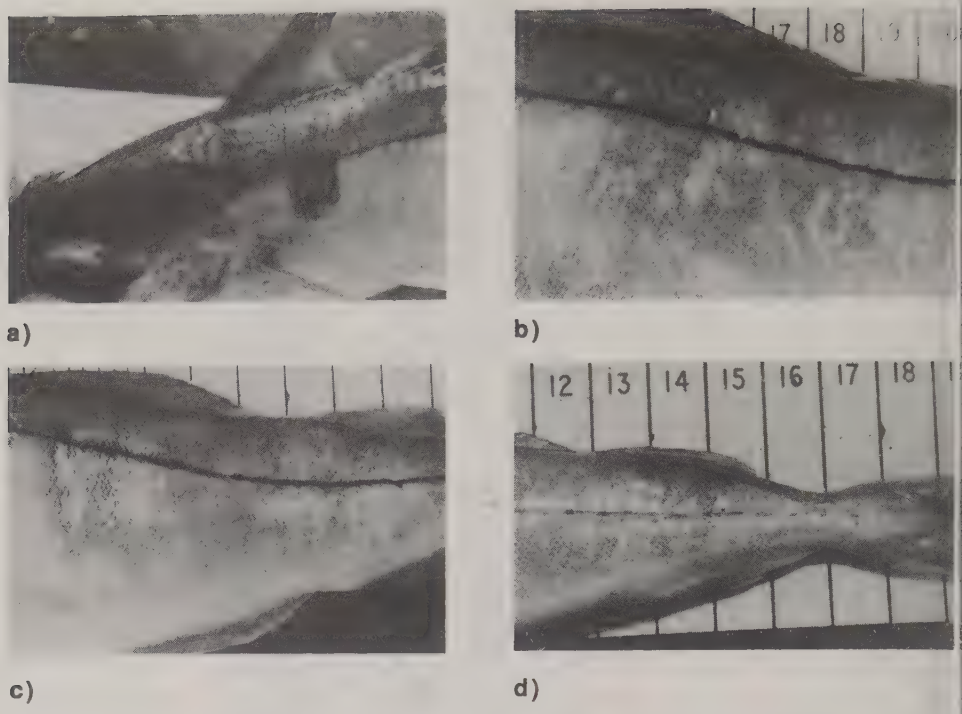


Plate VIII. a) Cod-end mesh damage around the dorsal fin.
b) Many small areas of scales missing.
c) Large areas of scales missing.
d) Large areas of scales missing near tail.

Comparing the haddock which had escaped with those which had not showed that less damage was caused to the retained fish in the 90 mm square mesh and 80 mm diamond mesh cod-ends but more damage in the 90 mm diamond mesh cod-end.

Observations on Cod-ends and Fish Behaviour

The diamond mesh cod-ends took up a bulbous shape as the increased drag of the catch pulled on the rear of the net (Plate II). The meshes were tight on all four bars and widest open just ahead of the accumulated fish mass, where most roundfish were seen to escape. At the narrow entrance to these cod-ends the meshes were almost closed, thu minimising the possibility of fish escape (Plate IX).

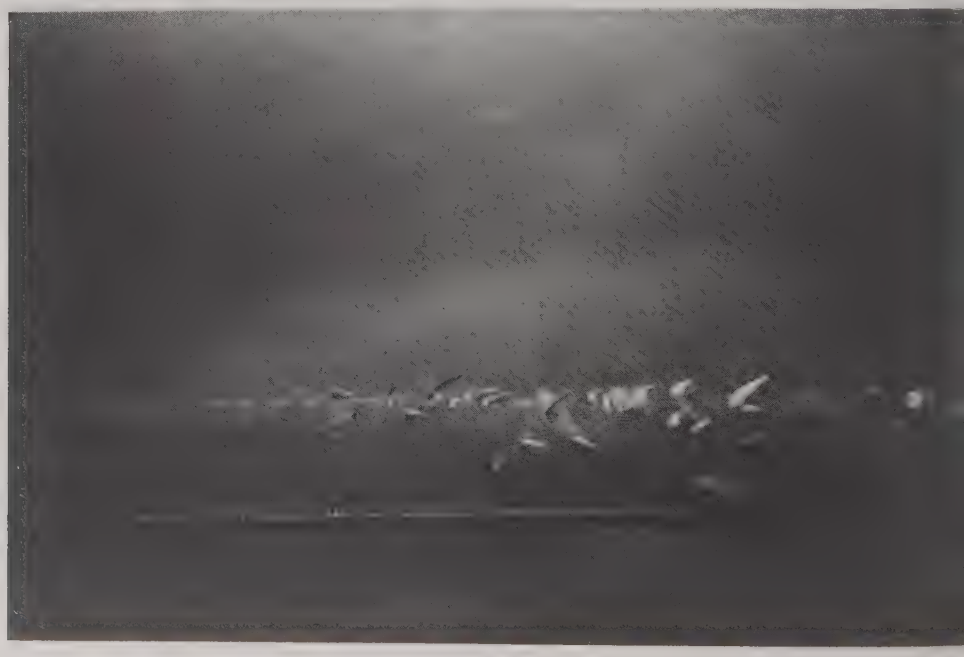


Plate IX. Fish trapped in the almost closed meshes at the narrow entrance to a diamond mesh cod-end.

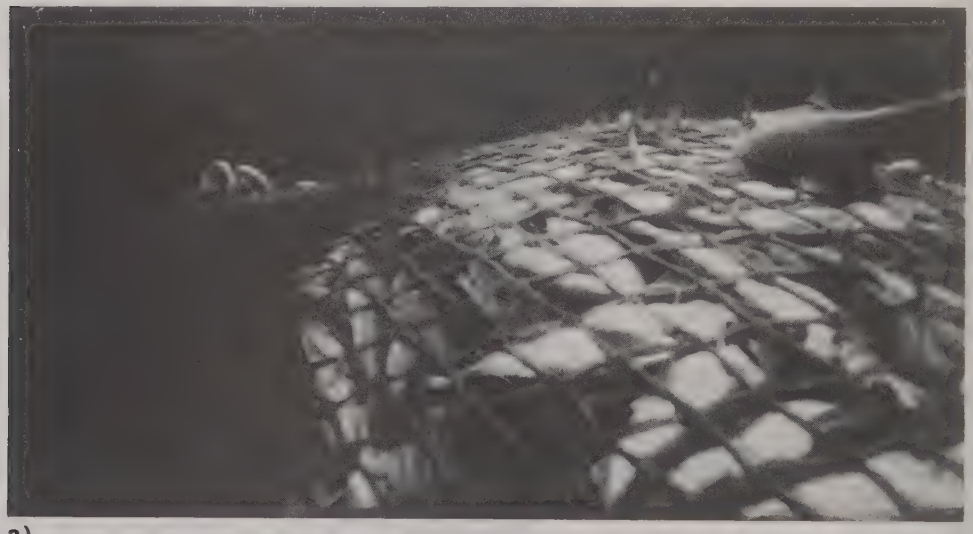
a)

b)

Plate X. **a) Rear section of a 90 mm square mesh cod-end demonstrating its open mesh cylindrical shape.**
b) Near the front of the same square mesh cod-end, the meshes are still wide open.

Observations on the square mesh cod-ends showed that all the meshes remained open throughout a trawl haul (Plates Xa and b). The sides of these cod-ends remained parallel as the catch increased, thus creating a long open uniform cylindrical shape. Many small haddock, whiting and cod (visually assessed at between 25 and 30 cm) were seen to escape without having to push through the mesh, but again escapes were mainly in the area just ahead of the accumulated fish mass at the rear of the cod-end. The strain on the square mesh was taken on the two side bars of each mesh which run fore and aft, whereas the bars across the water flow were bent with no apparent tension. If the catch was large, so that the accumulated bulk of fish pressed outwards on the walls of the square mesh cod-end, all four bars were seen to be under tension.

Many haddock, whiting and codling swimming in the front and central zones of the diamond and square mesh cod-ends were seen to tire, drop back to the rear of the cod-end, and lie pressed flat against the meshes owing to the flow of water. Some of these apparently exhausted individuals, in attempting to get off the meshes and recommence swimming, succeeded only in forcing their heads into open unblocked meshes (Plate XIa). As if an exit to freedom was sensed, these fish began a frenzied attempt to pass out through those meshes (Plate XIb). Depending on their girth, some were unsuccessful in escaping and remained meshed. Those that were successful (escape times ranged from 4 to 70 secs, Main and Sangster unpublished data) at the last moment before escape gave a number of rapid tail beats to ensure freedom. It was visually evident from this rapid tail flexing movement that most escaping fish incurred varying degrees of scale removal on both flanks, especially around the area of the caudal peduncle. However, not all escaping fish were subjected to such harsh treatment. Other observations in diamond and square mesh cod-ends revealed that some juvenile haddock, whiting and codling (estimated size range 25–30 cm) swam upwards rather than sideways and escaped with relative ease. It is not known whether this behaviour was intentional or by chance or whether the fish reactions were triggered by water flow. Owing to the speed of these fish escapes it was not possible to gauge the extent of their scale losses.



a)

b)

Plate XI. **a) The cod in the centre of the picture has pushed its head through an open, unblocked mesh.**
b) The same cod has now squeezed and wriggled its body almost out through the mesh. The unavoidably slow shutter speed of the camera, 1/30 second, can only capture this wriggling movement in a slight blurr.

Water Flow in the Cod-end and its Effect on the Catch

Diamond Mesh

As the fish catch increased at the rear of the diamond mesh cod-end,it eventually formed a solid mass obstructing the water flow. A turbulent circulation of water resulted, which carried all sizes and species of fish forward along the top sheet for 2 m, then downwards and backwards along the bottom sheet towards the main fish mass at the rear of the cod-end. During this enforced movement fish were seen to be tossed around, often striking the cod-end meshes and colliding with other fish and abrasive debris. Many were either forced out through the meshes (both head and tail first) by the turbulence or caught (Plate XII) half through the meshes depending on their shape and girth. Clouds of fish scales billowed around the code-ends. Fish that managed to swim ahead of the turbulence (by approximately 2.5 m) were seen to hold position. Here, haddock, whiting and codling (visually assessed at between 25 and 35 cm) remained low down, swimming near the belly sheet where weaker eddies were evident. These fish cannot maintain position at a towing speed of 1.5 m s^{-1} for more than one or two minutes (Wardle, 1977) and in these observations all fish tired and dropped back into the turbulent zone to the rear of the cod-end.

Plate XII. Fish being tossed around in the water turbulence resulted in many individuals being trapped half through the meshes of the 90 mm diamond mesh cod-end.

Square Mesh

Observations on the square mesh cod-end showed that as haddock and whiting dropped back they almost always struck upwards in an attempt to escape through the open top meshes of the cylindrically shaped cod-end. It was not clear whether this escape behaviour was due to (a) a different water flow in square mesh compared with diamond mesh cod-ends, or (b) the square shaped meshes being visibly more open to the fish. Furthermore, as with the diamond mesh cod-end, the turbulent water circulation was evident when the rear zone of the square mesh cod-end contained a sizeable fish catch, especially flatfish. From analysis of the video films it was concluded that greater numbers of haddock and whiting escaped or were thrown through the square meshes than from the diamond mesh cod-end. Scale damage was again evident in both haddock and whiting escapes in this type of cod-end.

Fish Behaviour and Survival in the Sea Cages (1985–1988)
1985 (80 mm Double braided diamond mesh cod-end)

The "control", "escaped" and "retained" categories showed no panic or escape activity whilst being transferred to the sea cage sites. Once inside the cages, all categories calmly explored the total area of their cage during the initial period of confinement. Only fish from cages A (escaped) and B (retained) (Table V) that were visibly scale damaged swam with an obvious degree of difficulty. A badly scaled individual would repeatedly sink momentarily to the sea bed, before swimming off again around the cage. Some fish, irrespective of which category, accepted food immediately; others required a day or so to commence feeding. The line caught "control" fish revealed only slight mouth injuries due to hook damage; otherwise these fish appeared to be in excellent condition. Daily counts of survivors in each cage during the 1985 experiment are presented in Table V. Divers removed the carcasses daily. Unfortunately, in 1985 cages A and B were lost in a storm and these experiments were prematurely terminated after 11 days. However, the divers' observations from the 11 day period gave evidence that eight surviving fish in cage A (escaped) had developed a form of body lesion in the scale damaged areas around the adipose and anal fins. This type of damage was not seen in the damaged fish in cage B, of which 86% survived. After 35 days, the control fish in cage C showed no visible hook injuries around their mouths and accepted food regularly.

Table V

1985 cage survival experiments. Numbers of live haddock counted from day one through to the termination of the experiments. Cod-ends made of double braided twine

Day	Escaped from 80 mm diamond mesh	Retained in 80 mm diamond mesh	Control
	Cage A Haddock	Cage B Haddock	Cage C Haddock
1	56	28	14
2	53	26	14
3	52	26	14
4	50	26	14
5	47	25	14
6	46	25	14
7	44	25	14
8	44	25	14
9	42	25	14
10	40	25	14
11	38	24	14
12	Bad Weather no count	Bad weather no count	Bad weather no count
13	Cage lost	Cage lost	14 (cage survived) the bad weather
35	–	–	14(fish released)
Haddock % survival	67%	86%	100%

1986 (80 mm double bradied diamond mesh cod-end)

One extra cage was introduced to investigate line caught damaged fish (cage B). This allowed observations to be made on damaged fish that had not been subjected to the trawling process. Daily counts of survival in each category are presented in Table VI.

Table VI

1986 cage survival experiments. Numbers of live haddock in each cage from day one through to the termination of the experiment. Data from 80 mm double braided diamond mesh cod-end

	Cage A (control)	Cage B (hand-line damaged)	Cage C (escaped from 80 mm diamond mesh)	Cage D (retained in 80 m diamond mesh)
Day	Haddock	Haddock	Haddock	Haddock
1	26	29	28	10
2	26	29	18	9
3	26	29	10	9
4	26	29	6	8
5	no count - bad weather	28	no count - bad weather	no count - bad weather
6	26	25	6	7
7	26	25	6	7
8	26	25	6	7
9	26	25	6	7
10	26	25	6	7
11	26	25	6	7
12	26	25	6	7
13	26	25	6	7
14	26	25	6	7
38	26	25	5	7
39	Cage turned over - no fish	Cage turned over - no fish	5	7
% survival (haddock)	100%	86%	18%	70%

Similar observations were obtained to those of 1985 showing that most fish, with the exception of 10 haddock in cage C (escaped), swam calmly around their cages in loose shoals and displayed no sign of agitation or panic behaviour in captivity (Plate XIII). The 10 damaged individuals in cage C did not shoal, remained apart and either swam lethargically, with repeated rests on the sea bed, or slowly swam high up near the roof of the cage. Healthy looking fish fed regularly and voraciously, whereas the damaged ones fed intermittently. The survival of fish in cage C (escaped) (Table VI) was very low (18%). Most haddock in this category failed to survive the first four days of the experiment even though the fish transport and handling techniques were strictly adhered to, whereas the controls (cage A) survived totally to the thirty-eighth day. In cage C, after the initial mortality, only one haddock died between day four and day 38. The "line caught damaged" fish in cage B survived well with the exception of four haddock in the first week. In cage D (cod-end retained), after a small initial mortality of three fish after the first 6 days, the haddock survived until counts ceased on day 38. On day 39 cages A and B were found overturned, presumably owing to commercial fishing activity in the area, rather than adverse weather conditions. Cages C and D survived, without any damage.

Plate XIII. The majority of fish swam calmly around the confinement of their cage.

Table VII

1987 cage survival experiments. Numbers of haddock in each cage from day one through to day 52. Data from 80 mm braided diamond and square mesh cod-ends

Day	Cage A (control)	Cage B (retained in 80 mm diamond mesh cod-end)	Cage C (escaped from 80 mm diamond mesh cod-end)	Cage D (escaped from 80 mm square mesh cod-end
1	23	60	46	53
2	23	50	38	52
3	23	48	24	46
4	23	47	20	46
5	23	41	16	46
6	23	41	15	44
7	23	41	14	44
8	23	41	14	41
9	23	41	13	41
10	23	41	9	41
11	23	41	9	40
12	23	41	9	40
13	23	41	9	40
14	23	41	9	40
15	23	41	8	40
16	23	41	8	40
17	23	41	8	40
18	23	41	8	40
52	23	40	0 (assumed)	40
% survival (at day 52)	100%	67%	0%	75%
% survival (at day 18)	100%	68%	17%	75%

1987 (80 mm double braided diamond and square mesh cod-ends

This year, an extra cage containing a group of haddock which had escaped through a square mesh cod-end, allowed survival comparisons to be made with haddock from control and diamond mesh cod-end categories (Table VII). All fish except the badly scaled haddock in cages B, C and D commenced feeding after day three. Badly damaged fish were seen as "distressed" individuals, either swimming in a head raised attitude near the sea bed, or swimming slowly near the top of the cage well away from the main loosely-shoaling group (Plate XIV). After two or three days, the scale damaged areas of these fish eventually turned a white colour visually resembling a type of fungus or thick layer of mucus. The tails of a few fish slowly began to rot away (Plate XV). Three haddock in cage C (diamond mesh escaped), showed abrasion wounds on their flanks and tails and eventually developed ugly dark red sores after day five. These three fish showed progressive deterioration, refused to accept food and eventually died between day six and day nine. Most deaths in cages B (diamond mesh retained) and D (square mesh escaped) occurred in the first three or four days, whereas in the control cage A all fish survived until the experiment ended on day 52. Cage C, although having a heavy fish mortality in the first three days (similar to cages B and D), continued to have deaths during the next seven days (unlike cages B and D).

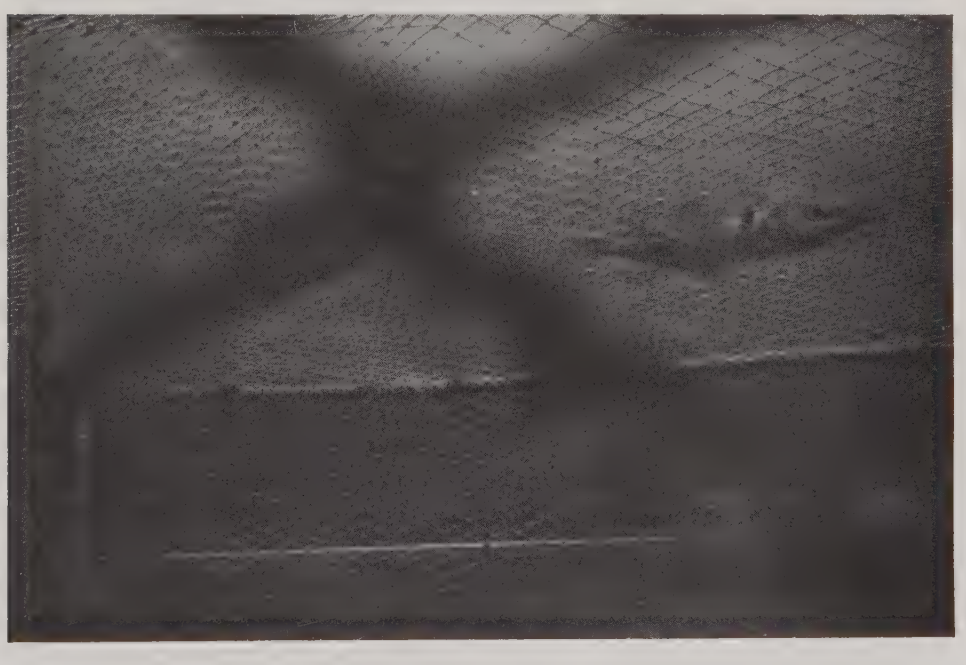


Plate XIV. Haddock swimming high up in the cage away from the main shoal. This individual was badly scaled along its flank.

Between days 18 and 52 one fish died in cage B and none in cage D, whereas no fish survived in cage C. Divers found no carcasses inside cage C and discovered no evidence of a possible escape route, so it was assumed that these last eight individuals (see Table VII, column-cage C) died and were eaten by amphipods and other invertebrates. On day 52 all surviving fish accepted food and only one haddock (cage B) showed an open sore below its left side lateral line which did not seem to impair either its appetite or its swimming ability. All other fish appeared healthy.

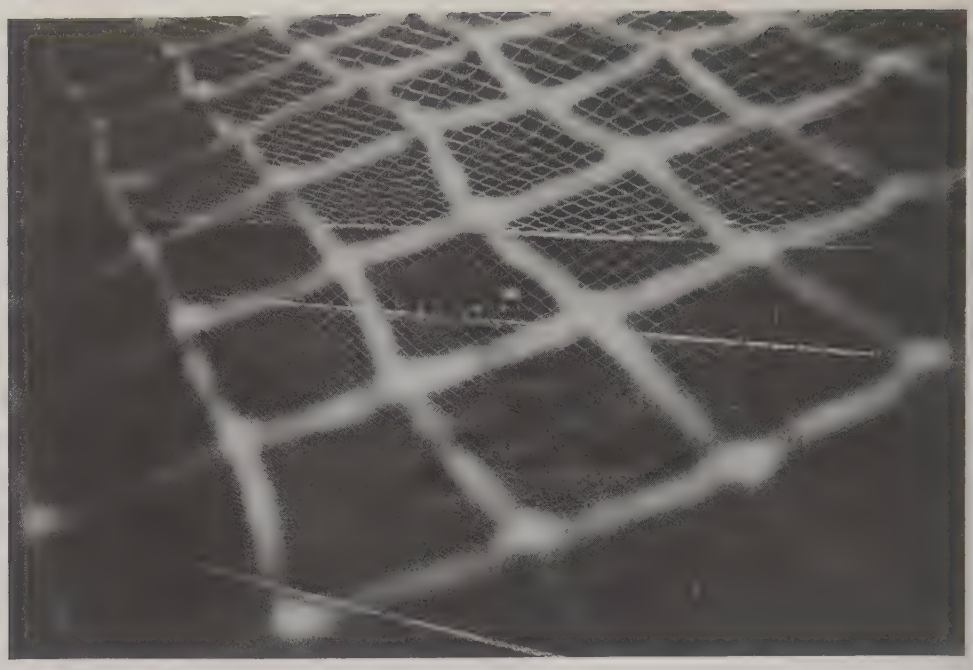


Plate XV. Haddock showing a type of white fungal growth on the scale damage area around the anal and tail fins.

1988 (90 mm double braided diamond and square mesh cod-ends)

The specially designed cod-end cover worked extremely well and did not obstruct the escape of haddock through the cod-end meshes. The cover was easy to detach under water, and whilst it was towed slowly to the sea cage site, the escaped fish were seen to swim calmly inside the cover. Furthermore, the transfer of the 30 fish from the cover to the appropriate sea cage was completed quickly and easily without further damage to the fish.

As in previous years, direct observations showed that the haddock settled down quickly in captivity after an initial exploratory period and most (noticeably the control fish) accepted food without hesitation after one or two days. All fish were feeding on day three. Damaged fish swam as individuals away from the main haddock shoal. Most deaths occurred in the first week and were measured for length and girth. Most were investigated externally and internally for a possible cause of death, and apart from the obvious areas of scale removal they showed no evidence of internal organ damage. The percentage survival of haddock after 26 days was calculated for each category of fish (Table VIII). The triplicated experiments show a satisfactory consistency. An analysis of variance indicated that the haddock survival rate for the diamond mesh escaped fish is significantly different from both the square mesh and the control fish ($P<0.01$) and the survival rate for the square mesh is significantly different from the control fish ($P<0.05$).

After fish counts were completed the fish were set free, the normal procedure at the end of the experimental work.

TABLE VIII

1988 final triplicated cage survival data for haddock using 90 mm diamond, 90 mm square mesh cod-ends and hand-line caught, tagged and untagged individuals

Fish category	Cage No	% survival	
		30 haddock (untagged)	10 haddock (tagged)
Escaped from 90 mm diamond mesh	1	67%	100%
	2	74%	100%
	3	73%	100%
Escaped from 90 mm square mesh	1	92%	100%
	2	92%	100%
	3	94%	100%
Control (hand-line caught)	1	97%	90%
	2	100%	100%
	3	100%	100%

Discussion

Although the numbers of haddock and whiting studied were small (310 and 73 respectively), the results showed that the amount of scale damage was not related significantly to fish size. Scale loss seems quite high at 20% or more, but it must be pointed out that these data related only to fish which were successfully caught by the divers after escaping. There may have been fish which escaped more easily and with less damage but were more difficult to catch. So the results may have shown the maximum percentages of fish scale damage likely to be sustained by the most lethargic fish during the escape sequence. It was clear, however, that most haddock, whiting, cod and hake greater than about 18 cm in length sustained some degree of scale removal during escape from cod-ends of these mesh sizes and that the damage to a particular size of fish had no single cause. Furthermore, the percentage scale losses for haddock and whiting escaping through similar sizes of diamond and square mesh showed no marked difference.

As the catch builds up at the rear of a cod-end the tension in the meshes increases. Diamond shaped meshes become more elongated, restricting the area of escape for fish, whereas with square mesh there is little reduction in escape area as the tow progresses. A second difference between these two mesh shapes is that the transverse bars in meshes ahead of the catch in a square mesh cod-end are slack and may be more easily deflected and hence less obstructive to the passage of a fish than the taut diamond mesh bars. For these reasons it might be expected that less damage would be caused to fish escaping from square mesh and that smaller fish would sustain less damage than large. There may, however, be additional factors to consider; as a fish turns to escape through a square mesh it is no longer aligned with the flow and may be forced against the rear bar as it passes through.

The deaths of fish in the keep cages cannot be ascribed unequivocally to scale damage during escape from the cod-end. Being held in cages with other fish may contribute to mortality, possibly through stress or cross-infection. The experimental methods, ie the use of control groups, the cage design and the Latin square cage layout, were designed to identify and minimise losses due to confinement in cages. Further, in 1988, the triplication of experimental groups indicated the variability of the measured survival rates. These were consistent

enough to suggest that tentative comparisons might be drawn between the survival rates of different groups, at least for 1988.

The 1988 results from the survival trials are encouraging. Survival rates for the experimental fish were high and almost all the control fish survived in confinement. The higher survival rates in 1988 may have been due to the different capture methods used earlier. In the 1988 survival experiments, all fish escaping from the cod-ends were collected in a loose cover and transferred to cages, whereas in the earlier scale damage trials divers caught the escaping fish in plastic bags. Prior to 1988, a biased sample of weaker fish may have been obtained. The 1988 survival results therefore, may be more representative of the whole population of escaping fish.

In contrast to the scale loss results, survival rates of escaped fish from similar sizes of diamond and square mesh were significantly different. Although Figure 4 suggests similar rates of scale loss, it is possible that the experience of the fish was significantly different in the two cases prior to escape. For instance, fish may have made fewer attempts to escape and may have been less exhausted in square mesh cod-ends. Caution is needed when comparing the survival rates of fish from square and diamond mesh cod-ends. The mean selection length of a square mesh cod-end is always higher than that of a diamond mesh cod-end of the same mesh size. Thus the length group of fish which have to wriggle through the meshes is different. If the fish population being sampled does not contain many large fish, then the fish escaping from the square mesh cod-end may do so with relative ease and suffer less scale damage. It might be realistic to compare the 1987 80 mm square mesh (Table VII, column 5) and the 1988 90 mm diamond mesh data (Table VIII, line 2). Survival rates are comparable, but as the data are from different years, no firm conclusion should be drawn.

The complete history of a fish during the capture process is complex, involving herding by the trawl and collisions with other fish, crustaceans and trash, as well as abrasion on the netting. These experiences will affect its physiological condition and behaviour when it reaches the cod-end and hence its chance of escape and ultimate survival. Studies are being undertaken to assess this physiological condition in one respect by measuring lactic acid and glycogen levels in fish muscles before, during and after confinement in a cod-end.

The dead fish removed from the cages showed varying degrees and types of external damage - missing scales, open sores, fungal growth or even no damage. In future work *post mortem* examinations will be conducted to identify the cause of death more precisely.

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We are most grateful for suggestions and constructive criticism on the manuscript from Mr R.S.T. Ferro and Dr P.A.M. Stewart. We also express particular thanks to our colleague, Mr W.R. Mojsiewicz for his technical help and expertise during this whole scientific study. Thanks also go to Skipper J. Slater and the crew of the commercial trawler "Aries" BCK126 for their willing help, patience and enthusiasm during many aspects of the work.

Summary An investigation is described into the scale damage suffered by young gadoid fish escaping from cod-ends and the survival rates of escapers held in captivity. The work took place from 1985 to 1988.

There was no clear relation between scale loss and fish length in the species examined. Scale loss was greatest at 70 mm, the smallest cod-end mesh size tested, and decreased with increasing mesh size. There was little difference in the scale damage to haddock escaping from square and diamond mesh cod-ends of similar mesh size. Scale loss tended to increase towards the tail in nearly all the fish examined. It was observed that most fish longer than about 18 cm suffered some scale loss during escape and that the damage was not due to a single cause.

Haddock escaping from the test cod-ends were caught, held in 17 m^3 cages on the sea bed and their survival rates compared with those of control groups of hand-line caught haddock. Scale damage is not the only possible cause of death in these captive fish. To increase confidence in the findings, triple experimental groups were used in 1988. The survival rates of the controls were 97–100%. For 90 mm diamond and square mesh cod-ends, which are not directly comparable as the latter has a larger mean selection length, the survival rates were 67–74% and 92–94%.

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